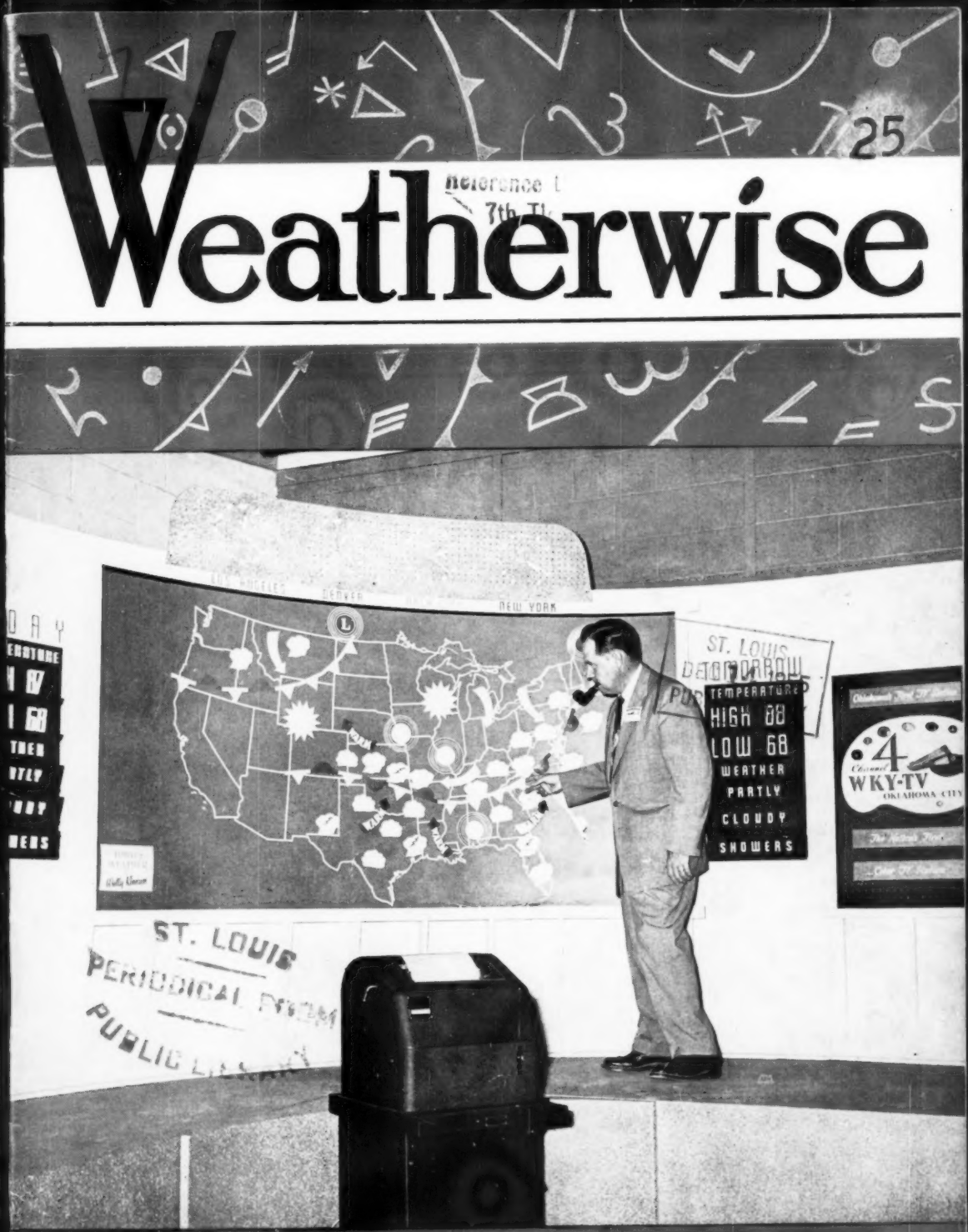
Weatherwise



Volume 8, Number 6 December 1955

"SOME PEOPLE ARE WEATHERWISE BUT MOST ARE OTHERWISE"—BENJAMIN FRANKLIN

WEATHERWISE

THE MAGAZINE ABOUT WEATHER

DAVID M. LUDLUM, *Editor* HENRY W. BULKLEY, *Associate Editor*

American Meteorological Society

Lapel Pin Design

A competition for a design suitable for an official American Meteorological Society lapel pin was announced recently. All members of the Society are invited to submit sketches to the Executive Secretary, 3 Joy Street, Boston 8, Massachusetts, to be received not later than 1 March 1956. Sketches should be in as detailed form as possible and suggested colors for any part of the pin should be indicated clearly. A special committee will be appointed to make preliminary judging prior to final selection by the Council. Suitable prizes will be awarded.

Eastern Snow Conference

The thirteenth annual meeting of the Eastern Snow Conference will be held at Dartmouth College, Hanover, New Hampshire, on 9–10 February 1956. All AMS members are invited to attend.

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Cover: The cinemascope weather board employed by Wally Kinnan, WKY's pipe-smoking meteorologist, at WKY–TV, Oklahoma City, Oklahoma. The board was recently demonstrated at Oklahoma's 1955 State Fair Exposition.

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Scientists associated with the Office of Naval Research engage in preliminaries to the International Geophysical Year by launching a rocket to explore the upper atmosphere near the North geomagnetic pole. Official Navy photo.

The USNC-IGY ANTARCTIC PROGRAM

PAUL A. HUMPHREY, *U. S. Weather Bureau, Washington, D. C.*

WITH the sailing of Naval Task Force 43 to Antarctica in mid-November, the United States commenced the first operational phase in one of the most important scientific endeavors ever undertaken—the International Geophysical Year of 1957–58. The IGY will represent the most comprehensive physical study of the Planet Earth ever put into operation. More than 40 nations are cooperating, and altogether the equivalent of tens of millions of dollars will be spent for special observations.

Paul A. Humphrey was USNC-IGY representative aboard the icebreaker U.S.S. ATKA on the reconnaissance of the Antarctic during January and February 1955. Much of this article is taken from the pamphlet entitled *Antarctic Program* prepared by the office of the Executive Secretary, U. S. National Committee for the International Geophysical Year, National Academy of Sciences.

The idea of international cooperation in the study of our constantly changing physical environment is not new. The importance of geophysical data gathered intensively and simultaneously over large and relatively remote areas of the earth was recognized in the last century in the conduct of the first polar

year in 1882 and 1883, when meteorological, magnetic, and auroral stations were established in Arctic regions.

A second international polar year was held in 1932–33, fifty years later. Probably the most important contribution of the second international polar year was the increased knowledge of the ionosphere, obtained by utilizing new radio sounding techniques. These contributions greatly advanced the science of radio communications, and it is difficult, indeed, to overstate their value now to our civilization.

The planned international effort for 1957 and 1958 surpasses in scope, intensity, and geographical coverage the earlier programs, which were limited largely to the North Polar regions.

The original suggestion for the IGY program came from L. V. Bergner. Writing in *Science* recently, he stated: "An international year serves two purposes: It provides an internationally agreed upon interval of unusual geophysical activity when it is especially profitable to occupy inaccessible areas, such as the Antarctic, for the purpose of supplementing the great continuing geophysical activities with observations in vital areas. And it provides opportunity for the geophysicists of the world to plan strategic networks for synoptic description of particular kinds of world-wide geophysical events, particularly meteorological, magnetic, ionospheric and auroral "storms" or disturbances whose spatial morphology and history are otherwise beyond our grasp."

The period selected for the IGY is one of considerable anticipated increase in solar activity, such as sunspots, and related disturbances in the various geophysical fields. Measurements and observations must be made simultaneously so that the relationships between fields can be determined on the basis of world-wide coverage.

Areas receiving special attention will include the Arctic and Antarctic Regions and the Equatorial Belt. In addition, chains of stations will be located along three longitudinal lines at 10° East, passing through Western Europe and Western Africa; 140° East, crossing Siberia, Japan, and Australia; and along 70° to 80° West through the Americas.

U. S. IGY Program

The United States plans activities at more than 300 stations in the Arctic, Sub-Arctic, middle latitudes of the Northern and Southern Hemispheres (including the continental United States, Central America, South America, and adjacent parts of the Atlantic and Pacific Oceans), Equatorial Pacific, and Antarctic and Sub-Antarctic Regions. The line at 70°–80° West Longitude is of especial interest to the United States since it crosses the eastern part of the U. S. and follows the continental land areas near 80° West in the Northern Hemisphere, skirts the west coast of South America in the Southern Hemisphere, and passes through the Antarctic Continent, terminating at the U. S. Pole Station at the South Pole.

USNC—IGY Antarctic Program

Since such inaccessible parts of the world as the Antarctic require exploratory expeditions as much as two years in advance, it was decided that the United States would establish stations during the fall and winter of 1955–1956 in the Antarctic in preparation for the scientific work to be done in 1957–1958. Rear Admiral Richard E. Byrd has been designated officer-in-charge of the U. S. Antarctic programs. Rear Admiral George Dufek is Commander of Naval Task Force 43, which is charged with the detailed operational planning and the conduct of the expedition.

During the winter of 1954–1955 the USS Atka made a voyage to survey the ice conditions adjacent to the Antarctic Continent and to find a favorable coastal site for establishing a base station. The 1955–1956 mission, called Operation Deepfreeze I, was organized to install the Little America Station and to transport equipment and supplies for the construction of two forward stations, the Pole Station at the South Pole and Byrd Station in Marie Byrd Land at 80° South, 120° West. U. S. plans include a logistics facility station at McMurdo Sound and stations on the Knox Coast and on the edge of the Weddell Sea as well as a station at Cape Adare occupied jointly by New Zealand and the U. S.

Under the over-all direction of Dr. Laurence M. Gould, Chairman of the USNC-IGY Antarctic Committee, scientists will conduct studies in the Antarctic in a number of

geophysical fields: aurora, cosmic rays, geomagnetism, glaciology, ionospheric physics, meteorology, rocket exploration of the upper atmosphere, seismology, and gravity measurements.

Aurora

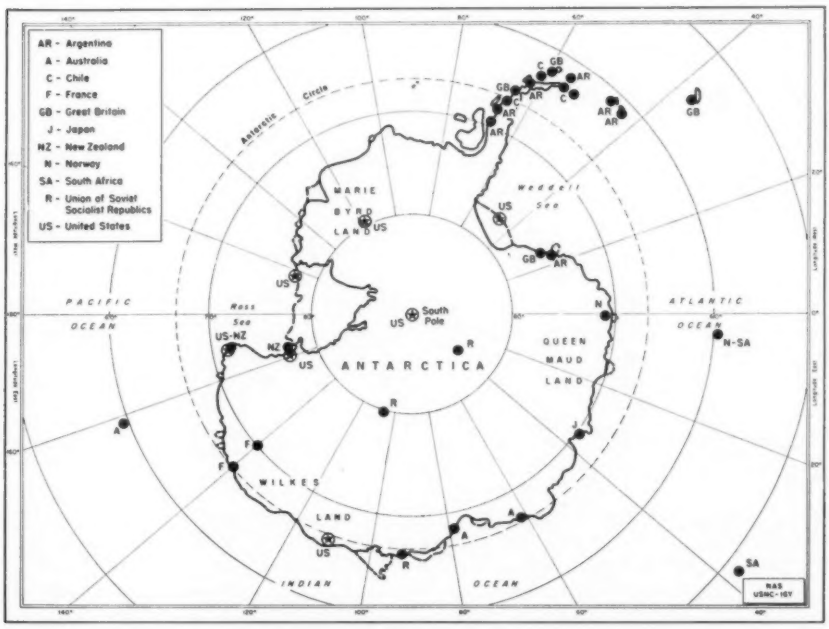
Bright streaks of light, searchlight-like streamers and luminous waving curtains in the sky, called the aurora, will be closely observed by IGY scientists. Atoms and electrons streaming from the sun, converge toward the earth's magnetic poles, penetrate the atmosphere, and excite the gases in the air. This excitation, in which atoms become more energetic, occurs about 60 miles high. When the atoms return to normal, they give out the distinctive lights and colors of the aurora. The entire action is similar to that which causes a neon tube to glow. Although the aurora is sometimes seen far from the poles, it is most often seen in a wide belt encircling the earth at about 23° from each geomagnetic pole. For this reason the polar regions are the best locations for observing the aurora.

In the Antarctic observers will study the timing, the rapid changes, and the geographical location of the aurora. They will break the light into its component colors, using spectroscopes and other equipment. A specially built wide-angle camera will take photographs of the sky almost from horizon to horizon at regular intervals. In addition, observers will make notes regarding the appearance of the aurora.

Cosmic Rays

Cosmic rays bombard the earth from all directions. Actually they are fragments of atoms coming from outer space and travelling at terrifically high speeds. They are observed with special "telescopes," frequently with a Geiger counter as the "eyepiece." Most cosmic rays are stopped high in our atmosphere, but they create additional fragments which reach much lower or even to the surface of the earth. Their energies are often much larger than what can be produced by the best man-made atom-smashers.

We learn a lot about cosmic rays themselves by observations of the number reaching the surface at different latitudes and their



The planned Antarctic stations for the International Geophysical Year which will be manned by teams of scientists from 11 nations.

The principal meteorological stations along the 80° meridian West which will be manned during the IGY. A similar watch will be maintained along the 10° East and 140° East meridians.

energies. And since the courses of these particles are affected by the earth's magnetism a large distance out, cosmic ray observations can tell things about the earth's magnetic field which cannot be learned from magnetic measurements on the ground. Some kinds of cosmic rays are also influenced by disturbances on the sun such as sunspots and solar flares or unusual and rapid changes in the earth's magnetism. By counting cosmic rays at various latitudes, altitudes, and times—and measuring their energies—we learn much about the earth, the sun's influence, and the number and type of these fragments which are dashing in their courses near the earth.

Some cosmic ray studies will be carried out continuously aboard ships en route to Antarctica and off the coast. At Little America two telescopes will also furnish continuous records. Balloons will frequently carry special cosmic ray instruments.

Geomagnetism

Geomagnetism is the study of the magnetic field of the earth and its variations. While its best-known practical uses are in surveying, navigation, and exploration for minerals and petroleum, geomagnetism plays a very important role in the study of the ionosphere, the transmission of radio signals, the aurora, and

cosmic rays. Variations in the earth's magnetism can be traced to two different causes: those occurring slowly over periods of years or decades result from slow changes in the earth's molten interior or in its crust; those happening rapidly come from electricity flowing far above the earth's surface, either in the upper atmosphere or even well above the atmosphere. The more rapid magnetic changes are usually associated with radio blackouts and auroral displays; they increase in number and intensity with an increase in the number of sunspots. The United States IGY geomagnetic program calls for systematic measures of magnetic variations at a large number of locations, including each of the stations in Antarctica.

Glaciology

About a tenth of the earth's land surface is covered by ice. Of this ice the glaciers located in Greenland and Antarctica have a very strong influence on the weather at remote parts of the earth. The IGY plans call for an unprecedentedly thorough exploration of the physical aspects of the Antarctic ice sheet and its extension into the ocean and the shelf ice.

Scientists will cover a very wide expanse of territory in the Antarctic. Holes will be drilled down to a record depth of 1,000 feet and snow samples taken, temperatures measured, and the age of the various ice layers estimated. While they will make very detailed studies in the vicinity of the fixed stations, during the summer they will also make long traverses to take spot measures of ice thickness, to study composition of snow and ice, and to map roughly the underlying land. The parties in tractor trains will be supported by air reconnaissance, mapping, and aerial photography. All these data will help unravel the relationships between glaciers and weather and, as by-products, the characteristics of snow and ice surfaces for supporting men and machines.

Ionospheric Physics

The ionosphere, a series of electrified layers of air between 50 and 250 miles above the earth's surface, makes long-distance radio transmission possible by reflecting radio waves back toward the earth. The ionization, or electrification, of this region is mainly caused by radiations from the sun. The ionosphere, and therefore short wave communications, is

A Signal Corps observer, Amory H. Waite, on the USS Atka expedition holds a piece of a wind generator he mounted 21 years ago atop a radio tower at the former Little America base of Admiral Byrd. Wide World Photos.

affected by solar and geomagnetic disturbances, by auroral displays, and possibly by meteors. Predicting the effect of these disturbances on radio communications is one of the major problems in applied ionospheric physics.

In the Antarctic radar-like soundings will record in detail the heights and movements of the layers as well as their radio reflecting properties. The unusually large and sudden changes during periods of disturbance will be studied by all stations, very closely coordinated, not only within the Antarctic but also throughout the world. At the Byrd station there will also be accurate recordings of atmospheric noise or radio "static" at several radio frequencies. These are radiations from far distant thunderstorms which travel to the observing station like radio signals by bounces between earth and the ionospheric layers. At times during the long polar night the static is expected to be weak; then the sensitive recorders will be able to detect radio noise from the Milky Way and the "radio stars."

Rocket Exploration of the Upper Atmosphere

Rockets provide an exceedingly successful technique for obtaining much valuable information in many of the fields of geophysics, which is not available to ground based observers. Even the small upper-air rockets can carry instruments to heights three times higher than balloons. They can make on-the-spot observations which check and improve the interpretation of the indirect measurements such as radar or the theoretical extrapolations of surface measurements.

A small but pioneering program of rocket exploration is scheduled for the Antarctic region. It will be carried out by means of rockoons (rockets released from balloons at top of ascent) from aboard an icebreaker en route to Antarctica and off the coastal ice shelf. These rockets are expected to reach an altitude of 60 miles and will carry instruments for experiments in geomagnetism, cosmic rays, and aurora.

Seismology and Gravity Measurements

Earthquakes and earth motions are the concern of seismologists. Virtually no measurements of this type have been made directly on the Antarctic Continent although it is known, from observations at distant stations, that important quakes have occurred in Antarctica or in the adjoining sub-Antarctic region. During the IGY there will be at least three fixed seismic stations at U. S. sites. In addition, seismologists will work closely during the summer with glaciologists in estimating the thickness of the Antarctic ice through observation of artificial earthquakes.

The true shape of the earth may be determined from measurements on the direction and strength of gravity at many stations over the globe. During the IGY these measurements will be made, with improved observational techniques, at many locations not usually accessible, including, of course, the Antarctic sites.

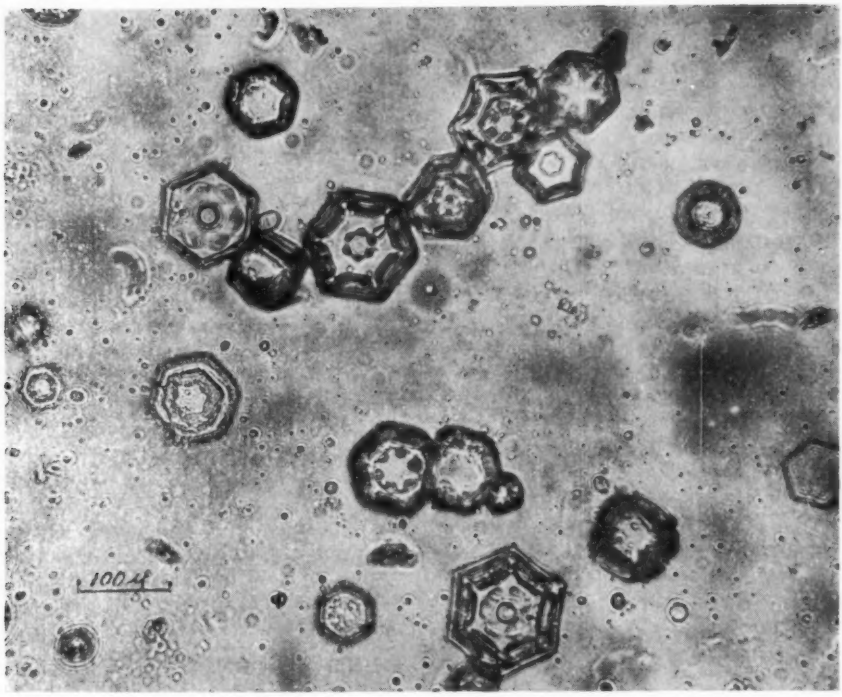
Meteorology

The atmosphere is the working fluid of an enormous engine which picks up heat in the tropics and discharges it in the polar regions. In the course of this complex process the atmosphere creates winds and weather. Meteorology, the science of weather, depends on regular observations over a wide spread area; and the planned global network of surface and balloon stations making weather observations, as well as the three pole-to-pole lines of meteorological stations at 70°–80° West, 10° East, and 140° East will greatly aid long-range weather predictions and the growth of knowledge of basic weather patterns.

A complete surface and balloon weather observation program is planned for all the U. S. stations in the Antarctic. Weather information will be obtained from the earth's surface up to as high as 100,000 feet or more. Limited weather information will also be collected on all over-snow traverses, and some weather observations will be made on aircraft flights.

Weather Central. In addition to a comprehensive meteorological program of surface and upper-air observations, a significant part of the United States International Geophysical Year activities in the Antarctic will be the operation of a Weather Central. During 1957–1958 this unit will function as a collection center for weather information from whaling vessels, expedition ships, aircraft, Antarctic stations and travelling parties, ocean islands, and stations in Africa, South America, Australia, and New Zealand. The

(*Continued on page 154*)



Ice crystals formed on silver smoke exposed to iodine vapor to produce an adsorbed layer of silver iodide. Photo by the author.

Simple Experiments in Atmospheric Physics—5

Silver Iodide as an Ice Nucleus

VINCENT J. SCHAEFER, *Director of Research, The Munitalp Foundation, Inc.*

THE common forms of tiny particles that float in the air and, under suitable conditions, act as centers for ice crystal formation are submicroscopic fragments of minerals and soils of volcanic origin. As mentioned earlier, most of these become active at temperatures colder than − 12° C. However, many natural soil particles are not effective in this role even at − 25° C.

SILVER IODIDE AS AN ICE CRYSTAL NUCLEUS

As of late 1955, silver iodide was the most effective foreign particle nucleus for ice crystal nucleation known to science. This property of silver iodide was discovered by Dr. Bernard Vonnegut, while working with me in the General Electric Research Laboratory early in 1947. Studying the X-ray diffraction properties of crystals, he found that this substance came closest to pure ice in its atomic pattern and dimensions.

When pure silver iodide crystals are ground to a fine powder and dusted into a water droplet cloud supercooled colder than − 4° C, ice crystals suddenly appear. If observed under high magnification, the ice crystals are found to be growing on the silver iodide fragments. Similarly, a thin water film such as a soap bubble when supercooled will immediately start freezing, if a single particle of silver iodide is dropped on it.

Methods of Producing Tiny Silver Iodide Particles

There are many different methods of producing silver iodide particles, most of which have been described by Dr. Vonnegut in his early papers on the subject. The simplest of all has already been mentioned. By grinding pure crystals of silver iodide, it is difficult to get particles much smaller than 1 micron. Such particles, although practically invisible under the light microscope, are still more than a thousand times larger in volume than is needed for effective ice crystal nucleation.

The easiest method for making silver iodide particles very small is to build them from individual molecules or atoms of silver and iodine. By heating powdered silver iodide in a flame, an electric arc, or a hot wire, the substance decomposes to silver and iodide. The chemical affinity of these two materials for each other is so great, however, that as soon as the vapor cools, great numbers of very tiny silver iodide particles form. Thus it is possible to take a thimble full of silver iodide powder (about 5 grams) and produce more than 1×10^{18} particles (1,000,000,000,000,000,000) each about 0.01 microns diameter. This is such a large number as to be hard to comprehend. If, however, each of these particles nucleated an ice crystal and grew to form an ice column such as falls from cirrus clouds (1 mm long), the sum total would produce one billion tons of snow! This would cover an area 100 miles square with about 10 inches of snow!

If these figures are correct, why then are we not being buried under great masses of snow, since commercial cloud seeders have put into the atmosphere many thousands of grams of silver iodide over the past few years? The answer is complex but is related to the decomposition of silver iodide, the capture of particles by precipitation, the filtering action of forests, and similar mechanical and chemical effects which are continually taking place in the atmosphere.

Simple Methods for Producing Silver Iodide Smokes for Cold Chamber Experiments

One of the simplest methods for making silver iodide smoke is to rub a little powdered silver iodide crystals on the wood near the tip of a match. After striking the match, and while it is burning, it should be momentarily passed through the cold chamber and then extinguished. As soon as a supercooled cloud is formed, myriads of twinkling ice crystals will replace the water droplets. Unless care is exercised in this procedure, the air of the room will become so loaded with silver iodide that ice crystals will form for several hours afterward, whenever a supercooled cloud is formed in the open chamber. A better control may be exercised by dusting a pinch of powdered silver iodide over a large piece of tissue paper and rubbing it into the surface. Tiny strips of this paper may then be ignited and dropped into the chamber. Cotton thread may be used in a similar manner.

Although silver iodide is one of the most water insoluble chemicals known, a solution in acetone of 30–40 per cent may be achieved by first preparing a solution of sodium iodide in the acetone. When silver iodide is then added in equal molal concentration, a complex salt forms as it dissolves. The dissolved chemicals form a clear yellow-colored solution.

A 10 per cent stock solution is easily made and may then be diluted with acetone to lower concentrations. Acetone burns, thus making it possible to make a smoke of silver iodide by igniting a cotton wick soaked in the solution, or, as is done by some commercial cloud seeding generators, by introducing the acetone solution directly into a flame of propane, alcohol, kerosene, or other combustible gas or liquid. Solid materials like coke, charcoal, rope, or paper may be impregnated with the silver iodide solution and subsequently burned after the acetone has evaporated. Any of these procedures may be followed on a miniature scale to conduct experiments in the laboratory or home cold chamber experiments. A little experience will quickly emphasize the care that must be exercised in forming silver iodide smokes, if one wishes to be free of persistent effects!

Experiments Illustrating the Chemical Reaction of Silver and Iodine

One of the most interesting and informative series of experiments with the cold chamber involves the reaction between silver and iodine.

An insulated wire fastened to a terminal of a battery should have its other end fastened, with solder or a metal clip, to a piece of silver such as a coin. Touched momentarily to the opposite terminal of the battery, a spark will form. This spark produces many submicroscopic particles of silver. If this procedure is carried out in a cold chamber and a supercooled cloud forms, no appreciable increase in the number of ice crystals will appear than was observed before sparking occurred. If some iodine vapor is then introduced into the chamber by passing a few crystals of iodine, or an uncapped bottle of tincture of iodine through the air, great numbers of ice crystals will replace the supercooled cloud. The iodine vapor becomes adsorbed on the silver surfaces to form silver iodide. Since only the surface structure is important, the particles formed in this manner seem to be as effective for ice crystal nucleation as pure crystals of the iodide and are active between $-4°$ C and $-5°$ C.

Silver Particles in Ordinary Air

One of the most interesting effects that may be demonstrated in the cold chamber is the concentration of silver particles in the air. The mechanism of ice crystal formation on silver iodide in a supercooled cloud is probably one of the most sensitive methods for detecting silver that is known in chemistry, since it is possible to demonstrate the presence of a single silver particle less than 0.01 microns in diameter. The procedure is simple. A small crystal of iodine should be placed on a glass surface in the chamber with the temperature about $-15°$ C. Before this is done, a supercooled cloud should be formed and observed for the presence of foreign particle ice nuclei. Ordinarily, at this temperature few, if any, ice crystals will be seen to form. Soon after the iodine crystal is put into the chamber, ice crystals will appear. The concentration varies from a few per liter to as many as a thousand per cubic centimeter. This variation of a million fold is dependent apparently on the source of the air. In a modern physical and chemical research laboratory, the concentration will reach or even exceed 1,000 per cc, due apparently to the sparking of silver coated electric relays, chemical processes, and electric sparks. Even in regions far removed from such concentrated sources of silver smoke, it is possible to get definite effects. In my home laboratory, a few crystals of iodine, together with a continuous moisture supply to replenish the supercooled cloud, produces a continuous miniature snowfall on the bottom of the chamber.

Thus far, the only procedure I have found that eliminates this effect is to put the iodine crystals in a closed chamber such as the continuous diffusion type cloud chamber (which I shall describe in a later section of this series). Since this device isolates the air sample from further contamination, the silver effect slowly disappears as the particles react and precipitate to the bottom of the chamber.

The study of silver and other metallic iodides, as well as other rarer substances that serve as foreign particle nuclei for ice crystal formation, is a subject which can only be touched upon at this time. The research work in this field has started only recently. Many fascinating problems perplex the investigator. Important discoveries will be made during the next few years. The field is wide open.

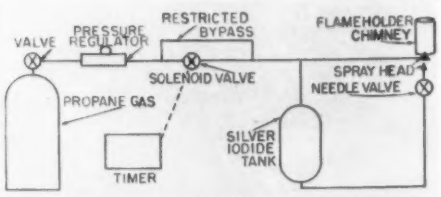
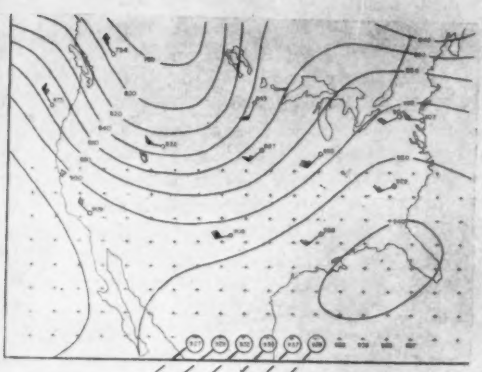


FIG.1-SCHEMATIC DIAGRAM OF GENERATOR

A late model silver iodide generator which will operate unattended for more than 100 hours. It is propane fueled.

FLOW OF INFORMATION IN A NUMERICAL FORECAST

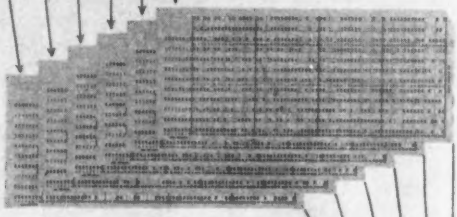
INTERPOLATED DATA AT STANDARD POINTS



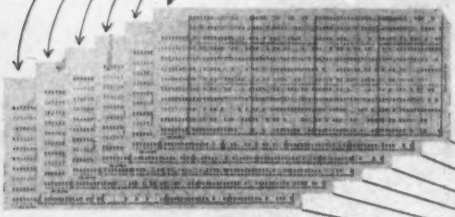
FORECASTING EQUATIONS

$$\frac{\partial}{\partial t}\nabla^2\Phi_{k+\frac{1}{2}} + J\left(\Phi_{k+\frac{1}{2}}, \frac{1}{f}\nabla^2\Phi_{k+\frac{1}{2}} + f\right) - f^2\left(\omega_{k+1} - \omega_k\right) = 0$$

$$\frac{\partial}{\partial t}\left(\Phi_{k+\frac{1}{2}} - \Phi_{k-\frac{1}{2}}\right) - \frac{1}{f}J\left(\Phi_{k+\frac{1}{2}}, \Phi_{k-\frac{1}{2}}\right) + \sigma_k\omega_k = 0$$



DECK OF CODED INSTRUCTION CARDS



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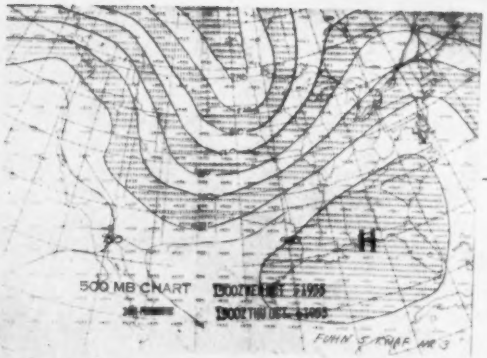
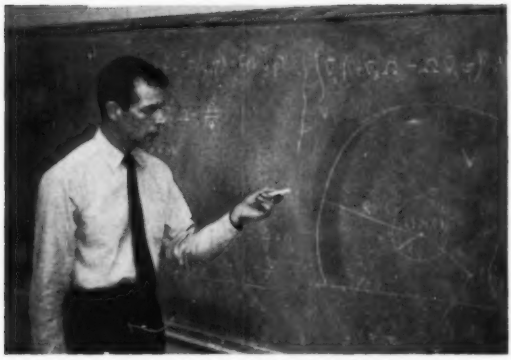


FORECASTING CONTOURS OF STANDARD ISOBARIC SURFACES

HIGHSPEED AUTOMATIC COMPUTING MACHINE



The author explains with chalk.

DYNAMICAL PREDICTION—

the Rational Approach to Weather Forecasting

PHILIP DUNCAN THOMPSON, *Major, U. S. Air Force,*
Joint Numerical Weather Prediction Unit,
Washington, D. C.

HIDDEN away on the top floor of an unpretentious yellow-brick building in Suitland, Maryland, is a room filled with banks of cathode ray tubes, electronic circuits, spinning drums and reels, and flickering control lights. This impressive array of gadgetry, a computing machine of tremendous speed and flexibility, is one of the world's first automatic weather forecasters. Day in, day out, it plots and predicts the motions of the great whirling air masses that make our weather—not, to be sure, by rule of thumb, but by carrying out the millions of numerical calculations required to solve the atmosphere's complex equations of motion. These machine-made predictions already play an indirect part in the preparation of local weather forecasts in your own region, and will play an increasingly important and direct role in the entire practice of weather forecasting in the future.

The development of theory and computing technology that has made automatic weather prediction (or "numerical weather prediction," as it is usually called) a working reality has been one of the most significant and spectacular advances in meteorology in the past thirty years. The methods on which numerical weather prediction are based have not only shown promise of improving the accuracy of routine weather forecasts, but have also proved to be extremely powerful tools for dealing with a variety of research problems, some of them not immediately related to fore-

casting. In fact, judging from the present rate at which the application of these methods is widening, it is probably safe to say that the development of numerical weather prediction marks the beginning of a technological revolution in meteorology.

The purpose of this article is simply to explain in general terms what numerical weather prediction is, and to hit a few of the highlights in its evolution over the last half century.

Although the application of mathematical methods to weather forecasting may appear revolutionary, the methods themselves are certainly not. They are exactly analogous to the methods by which the astronomer predicts the positions of the planets from Newton's laws of motion, the aerodynamicist computes the flow around an aerofoil from the laws of fluid dynamics, or by which the theoretical physicist predicts the outcome of a violent nuclear reaction before it is started—all of which have met with considerable success in the past. In each of these instances, the physical principles that govern the behavior of the material in question are known rather completely, and can be expressed in the form of mathematical equations. The central problem in these cases, as it is in all well-developed branches of physical science, is simply to formulate the governing equations in such a way that they can be solved easily, and to compute their solutions accurately.

That the latter is also one of the central problems in meteorology and weather forecasting has long been recognized. As early as 1904, in a truly remarkable testament of meteorological faith, Vilhelm Bjerknes declared that the only rational approach to the weather forecasting problem lay through solving the so-called hydrodynamical equations, which, in their general form, express the physical laws governing the behavior of *all* fluids. There was, of course, no reason to believe that a fluid like the atmosphere is any less subject to the general laws of hydrodynamics than the air in a wind tunnel. Accordingly, it appeared only natural and logical to borrow a methodology that had been successfully employed in other branches of physical science, and to apply it to the problem of meteorological prediction.

The fundamental principles that govern the behavior of the atmosphere and which provide the physical basis for the methods of numerical weather prediction are well established, and are probably familiar to any college physics student. They are Newton's laws of motion, the principle of mass conservation, the first law of thermodynamics, and the Boyle-Charles law. The first of these simply states that the rate at which a body (of air) accelerates is proportional to the net force acting on it, and inversely proportional to its mass. The second expresses the fact that a net flux of mass into a fixed volume must be exactly accounted for by an increase in density within that volume. The first law of thermodynamics states that the heat energy added to a gas must be equal to the work done by the gas in expanding against pressure forces, plus the change in its internal energy ("temperature" energy, or energy of molecular unrest); common manifestations of this principle are the cooling of compressed air as it escapes from a tank or cylinder, and the heating of air as it is compressed in a bicycle pump. The Boyle-Charles law relates the pressure in a gas to its temperature and density.

The physical principles stated briefly above can be expressed in exact mathematical form as a set of five differential equations. These are the hydrodynamical equations referred to earlier. If the rate at which heat is absorbed or emitted by the atmosphere is known, this set of equations is said to be complete, in that it involves just as many variables or unknowns as there are equations in the set. In this case, the solution of the hydrodynamical equations is completely determined by the state of the atmosphere *at a single instant.* Thus, a solution that agrees with all the weather observations taken at one time constitutes a forecast of the state of the atmosphere at all future times. The fundamental problem of numerical weather prediction is to compute such solutions of the hydrodynamical equations, and numerical weather prediction itself is the process by which the equations are solved.

The hydrodynamical equations have been known for over a hundred years, and have been used in the study of meteorological problems since the time of von Helmholtz (1858). One might wonder, then, why the recent de-

velopment of numerical weather prediction did not take place a half century earlier. One very good reason is simply that there were (and still are) no methods of exact mathematical analysis for solving the general hydrodynamical equations. Accordingly, the efforts of Bjerknes and his contemporaries were confined to solving the equations in approximate form; that is, they were forced to introduce such approximations or simplifications as were necessary to make the equations solvable by the limited mathematical methods at their disposal. An equally strong deterrent to success was the lack of observations to test the validity of these approximations, either by preliminary estimate or by direct verification of their mathematical consequences. As a result, the early studies of Bjerknes and his co-workers, although they were a truly monumental contribution to our general understanding of the *kinds* of motions that occur in the atmosphere, did not reach to the core of the numerical prediction problem.

It was not until early in the 20th century that meteorologists fully realized that solutions of the general hydrodynamical equations could be computed from a network of simultaneous meteorological observations by *purely numerical* methods. During World War I, L. F. Richardson—a highly original British mathematician and meteorologist—devised a finite-difference method for solving the general equations, and published the results of the first genuine effort in numerical weather prediction in 1922. His results, to put it mildly, were not very encouraging, for they indicated that the large-scale pressure patterns travel at about the speed of sound, many times the observed speed of the migratory weather systems. Unfortunately, this was widely regarded as a crucial test of the theoretical approach to the forecasting problem, and there was widespread pessimism about the possibility of predicting weather by Richardson's method or, for that matter, by any mathematical method. Moreover, Richardson himself estimated that it would take around 64,000 people armed with desk calculators merely to "compute" weather as fast as it happened, let alone gain on Nature. In the face of such difficulties, interest in numerical weather prediction withered and lay dormant for almost twenty years.

The renaissance of numerical weather prediction began sometime around 1940, when the quality, geographical density, frequency, and vertical extent of meteorological observations first permitted detailed descriptive studies of the atmosphere's behavior on a very large scale. These studies indicated that many aspects of the general behavior of the atmosphere are not essential to its weather-producing mechanism and, accordingly, suggested ways in which the general hydrodynamical equations could be simplified without sacrificing their ability to describe the "meteorological" features of the atmosphere.

Three analysts of the JNWP unit study pressure contours. Left to right: Lt. Com. Moreland, Navy; Mr. Bristor, Weather Bureau; and Lt. Hubert, Air Force.

A second, and probably decisive factor in this rebirth of interest in numerical weather prediction was the development of high-speed automatic computing devices. By 1946, there were several electronic machines in various stages of design and construction, all of them capable of carrying out numerical calculations at about 10,000 times human speed. Realizing that Richardson's earlier computations could now be duplicated in a matter of hours, rather than months or years, theoretical meteorologists were quick to seize on the potentialities of high speed computing machines. Beginning late in 1946, a group of mathematicians and meteorologists at the Institute for Advanced Study in Princeton began to formulate the problem of solving the hydrodynamical equations by numerical methods, coupled with high-speed computing techniques.

At the very outset of this program, however, the Princeton group recognized that something must be done to avoid falling into Richardson's errors. They soon discovered that numerical solution of the general hydrodynamical equations is made difficult by the fact that they possess solutions corresponding to sound waves and other high-speed disturbances; broadly speaking, it was found that one must provide enough time-resolution to trace the progress of the most rapidly moving disturbances whose existence is admitted by the equations. On the other hand, one cannot conceive that the mere existence of sound waves has any significant effect on the course of meteorological events. It is natural, therefore, to inquire if the equations can be modified in some way such that solutions corresponding to sound waves (and other high speed disturbances) are excluded, but such that the "meteorological" content of the equations is left essentially intact. This question, which has been one of the main theoretical problems in the development of numerical prediction methods over the past seven years, was first treated systematically and in general terms by Charney. In 1948, he discovered that the consistent introduction of certain types of approximations into the hydrodynamical equations has precisely the effect of excluding or "filtering out" the solutions which are irrelevant and undesirable from a meteorological standpoint.

Since 1948, this and similar methods of "filtering" have been extended to increasingly general equations of atmospheric flow by Eady, Eliassen, Sawyer and Bushby, Charney and Phillips, and by the author. Numerical methods for solving the modified equations are developed to a high degree, and the coding of these computational procedures for high-speed machines is now a matter of routine. In fact, the underlying physical and mathematical theory of numerical weather prediction has now advanced to a point where the main problem is one of testing the theory and exploiting it for practical purposes.

In the past few years, some of these methods of numerical prediction have been subjected to test under a great number and variety of weather conditions. The simplest method is based on the equations for the "barotropic model"—an idealized atmosphere whose density is uniform and whose motions are purely horizontal. Despite their apparent crudity, the equations for the barotropic model have been found to account for most of the day-to-day changes in the pressure and flow patterns in the middle troposphere, and pressure forecasts based on those equations have proven to be quite as accurate as those prepared by conventional subjective methods in the hands of a trained forecaster.

As expected, it was also found that the barotropic model does not exhibit some of the essential meteorological features of the atmosphere. The motions of this simple model are governed by a single dynamical law—the principle of vorticity conservation, due to Rossby—which states that each small volume of fluid retains its original rate of rotation or spin throughout its subsequent history. This implies that the number and intensity of well-defined cyclonic and anticyclonic vortices in the barotropic model does not change from one day to the next and, accordingly, implies that the equations for this model cannot predict the creation and growth of *new* weather disturbances. Viewed in still another light, the barotropic model contains no mechanism by which potential energy can be converted to the kinetic energy of an intensifying cyclone or anticyclone.

These shortcomings have been remedied in a more general type of model, developed by a number of workers in the years 1952 and 1953. Unlike earlier models, this type is subject to the effects of vertical motion and as-

sociated thermodynamic processes, and provides a mechanism for feeding energy from an already existing supply of potential energy into an incipient disturbance. By early in 1953, methods of numerical prediction based on several variants of this type of model had been tested in specially selected cases of rapid cyclogenesis, and were found capable of forecasting at least the correct trend of the changes. Since cases of intensification and cyclogenesis are notoriously hard to handle by subjective methods of forecasting, it became apparent that the methods of numerical weather prediction were potentially superior and had already been developed to the point where they were of some practical value.

In judging the intrinsic worth of numerical methods, one must be aware that there is a real distinction between this approach and the subjective or empirical methods in common use. It is simply that the latter do not rest on any established substructure of theory. Thus, each empirical method is essentially an independent hypothesis and, when it fails, it fails completely. The errors of numerical prediction methods, on the other hand, are traceable to approximations that have been introduced into the equations with malice aforethought, and can be corrected by solving the equations in more general form. In short, when something goes wrong, we are not at a complete loss as to which way to turn next. One should expect, therefore, that the methods of numerical weather prediction will evolve gradually and continually toward greater generality, and that this evolution will be attended by a corresponding increase in forecasting accuracy. Finally, since the capabilities of the crudest methods of numerical prediction are comparable with those of subjective methods, it is probable that more general methods now in an advanced stage of development will bring about a significant increase in accuracy in the foreseeable future.

With these facts in mind, the Joint Meteorological Committee of the Joint Chiefs of Staff began to lay plans to put numerical weather prediction on an operational, routine basis. The planning and preliminary organization of an operational unit were completed late in 1953, and the Joint Numerical Weather Prediction Unit (JNWPU) was officially established in July 1954.

The JNWPU is a cooperative effort, jointly staffed, financed, and administered by the three government weather services—the Air Weather Service, the U. S. Weather Bureau, and the Aerology Branch of the U. S. Navy. Its primary function is to produce daily numerical weather forecasts for an area covering North America and the surrounding ocean areas, and for periods ranging from 24 to 72 hours. Because the methods of numerical prediction are by no means stabilized, the JNWPU also has the function of improving old methods and developing new ones.

As indicated earlier, both of the functions stated above require a high-speed computing machine. The JNWPU has the use of an IBM 701—one of the few production models that has the necessary speed and memory capacity. This machine can store several thousand numbers in its "internal memory," transfer data into or out of its memory within a few millionths of a second, and carry out numerical operations (e.g., addition, subtraction, multiplication) at the rate of thousands per second. Once it has the weather data in suitable form, it takes about an hour to compute 24-hour forecasts of the heights of the 1,000, 700, and 500 millibar surfaces and the vertical air speed at intervening levels.

Up until recently, the machine could forecast only from manually prepared data. Now, however, almost all of the operations involved in numerical forecasting are carried out automatically. The machine processes weather data which have previously been edited and recorded in standard form, computes its forecast, and prints out its results in the form of "machine-drawn" prognostic charts. To remove the meteorologist's last shred of dignity, the JNWPU is developing an automatic data input system, whereby the machine will edit weather data punched on a teletype tape, decode it, translate it into standard numerical form, and then proceed with its forecast.

The handwriting is on the wall: Many of the functions of the presentday weather forecaster—skilled as well as routine—will be taken over by machines.

A more detailed description of the organization, functions, and operations of the Joint Numerical Weather Prediction Unit will be presented in a forthcoming article in "Weatherwise." (Ed.)

Weatherwatch

Autumnal Heat and Hurricanes

DAVID M. LUDLUM, *Editor*

The summer of 1955 will be remembered by a large portion of the American population for its heat. In northern and central sections mean temperatures were at or above the extremes of record for both July and August. In the West the heat did not set in until the latter part of the summer, but once established, it created records for absolute maxima and continued into the fall when many late-season marks in the Great Plains were set. The sections which did not swelter unduly were the Southeast and Gulf Coast (where 1954 had been a scorcher) and the Northwest Pacific Coast, which has been cool for many months.

The summer's pattern of anticyclonic dominance of the weather map persisted into September; the principal feature was the large continental high which had appeared in late June. This area showed a tendency to shift westward as the summer progressed. By the late August–early September period the center had moved from the Gulf states area to the Southwest over New Mexico and Arizona, an unusual circumstance, which accounts for the "unusual" weather experienced in California during the first week of September.

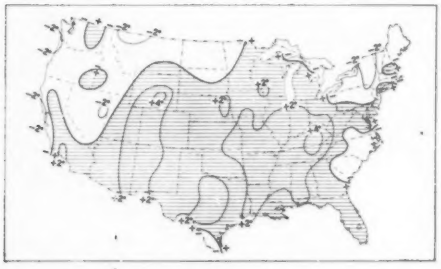
Throughout most of September the anticyclonic belt across southern and central United States, which one associates with summertime conditions, dominated the circulation pattern, giving a high index type. Pressure everywhere in the United States averaged above normal; the reverse was true in Canada where an active cyclonic center was over Baffin Land with another center a long distance to the west in the Behring Sea between Alaska and Siberia. A small ridge separated these in western Canada. The main storm track of the month was far to the north where the principal jet stream and fast westerlies were found, but as the month progressed the westerlies worked their way southward.

Air flow over the United States was mainly from the southwest after the 15th when a trough took form over the Pacific States. This brought a flow of warm air over the Mississippi Valley and the Northeast, so that the first part of the autumn season was very pleasant for outdoor activities. Most football fans in the East would not agree with the above statement as the passage of cold fronts seemed timed to occur on Saturdays, there being four out of five rainy football weekends at the start of the season.

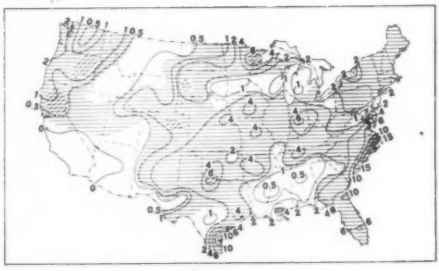
During the first two weeks of October the flow pattern established in the latter part of September continued to develop as the Pacific States trough, now further west off the coast, deepened and pressure was below normal northwestward to the Gulf of Alaska. At the same time the ridge over the Southeast intensified, again reinforcing a southwesterly movement of air over all central and northern sections east of the Rockies. During this period late season heat records were set in the Great Plains.

After mid-October several deep troughs moved eastward from the Pacific Ocean, giving copious rains over the southern Plains where the moisture was required for fall plantings. One of these troughs moved into the Great Lakes area and

MONTH OF SEPTEMBER 1955



Departure of Mean Temperature from Normal in degrees F. USWB chart.



Total Precipitation in inches. USWB chart.

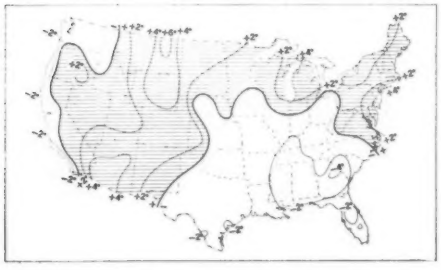
stalled as high pressure built up over Labrador and Quebec. This changed the entire circulation over eastern North America and marked a definite break from the early fall pattern. Thereafter, cold air was drawn southward from the Arctic into the Mississippi Valley to give the weather map a wintry appearance for the first time. The trough of the 14–16th finally became orientated west and east and led to very heavy rainfall in southern New England. Another trough followed and deepened in the Mississippi Valley; the subsequent northerly flow dropped temperatures well below freezing over a large area of the central and northern United States. Still another trough deepened in the same area on the 28th and caused widespread rain and snow. At the close of October an active weather map was in progress, presaging an early visitation of wintry conditions—this confirmed the prediction in the Old Farmers' Almanac that 1955–56 would be a severe winter, or, at least, that the early part would be severe. Circulation patterns, however, usually do not continue more than six consecutive weeks, and the character of the middle and late winter might be quite different.

LOS ANGELES HEAT—While many parts of the eastern and central United States were baking under the hottest combined July–August period in the record books, the area west of the Continental Divide had a delightfully cool period. Temperatures were much below normal in July, and in August the coastal areas still remained below, though the eastern heat area penetrated westward as far as the Sierras. The Great Valley and the interior of California were hot, but not abnormally so, during most of August, while the coastal areas were under the influence of a maritime flow from the southwest which kept readings in the comfortable 70s and 80s. Finally, on the last day of August, the heat from the interior broke through all the way to the coast and scorched the Los Angeles area with the highest reading ever reached in Weather Bureau history—110° at the downtown Weather Bureau on 1 September. This exceeded the old mark established in July 1891 by one degree! A comparison between the maximum thermometer readings at the downtown office, 10 miles from the ocean to the west, and at Los Angeles Airport only 3 miles from the shoreline, is of interest:

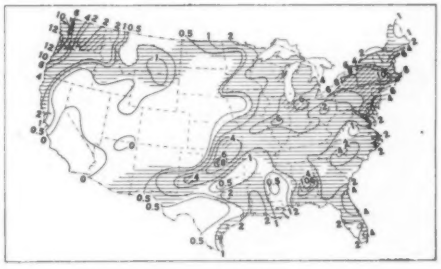
	Downtown	Airport
30 Aug.	88	79
31 Aug.	101	98
1 Sept.	110	108
2 Sept.	108	104
3 Sept.	103	92
4 Sept.	101	84
5 Sept.	100	83
6 Sept.	102	89
7 Sept.	100	92
8 Sept.	96	89
9 Sept.	88	78

CONNECTICUT FLOODS AGAIN—A rather weak trough entered the Pacific Northwest late on 9 October and moved at a leisurely pace across the northern tier of states, reaching the Great Lakes area on the 13th where it deepened considerably and became a major disturbance. Its normal eastward movement had been slowed and then actually blocked by a high pressure area which built up over the Quebec-Labrador region and pushed a mass of cold Arctic air into southeastern Canada and northern New England. The southern part of the trough continued to move eastward, pivoting around the stalled center in the lower Great Lakes area. When the trough became orientated west and east, it separated very cold air over the extreme northeastern United States from very warm, moisture-laden air over the Middle Atlantic States and adjacent ocean areas. This created a dangerous precipitation situation, and very heavy rains fell again from eastern Pennsylvania, across southern New York State, and into southern New England, the same area which had suffered from the excessive rainfalls of Connie and Diane.

MONTH OF OCTOBER 1955



Departure of Mean Temperature from Normal in degrees F. USWB chart.



Total Precipitation in inches. USWB chart.

Western Massachusetts and western Connecticut, along with parts of southeastern New York, were the centers of the excessive rain belt on this occasion. The largest areal rainfall and the greatest flood damage was concentrated in southwestern Connecticut with the cities of Danbury and Norwalk being the chief sufferers. Storm totals for the 14–17th, as reported by Paul Kangeiser of the Boston Weather Bureau, ranged up to 13.88 inches at Round Hill, Connecticut. Amounts exceeding 10 inches were also reported from points in Massachusetts and Westchester County, New York. Coming on the heels of the excesses of last August, the State of Connecticut once again reeled under the impact. Many highways and bridges which had just been reopened were destroyed by the new deluge. The New Haven Railroad had its entire main line roadbed washed out near Glenbrook, Connecticut, closing the four-track line for four days, the only direct railway link between New York City and Boston. Full service was not restored for seven days.

The record books demonstrate that this seemingly flood-proof area without major rivers or lake systems has been subject to disasterous flooding in the past. Under somewhat similar meteorological conditions, a downpour dumped 10.30 inches in 33 hours on Southington, Connecticut, in July 1897. Amounts of over 9 inches were measured at the cities of Bridgeport, Hartford, and Windsor in this storm. July 1897 was a very rainy month in southern New England. Southington had a monthly fall of 19.90 inches, and the 16-inch contour ran northward from Bridgeport on Long Island Sound to the Westfield area in western Massachusetts. The rainfall distribution was much the same as in the recent October 1955 disaster.

The State of Connecticut is well situated from a geographical point of view to receive excessive rains. When warm tropical air moves northward over the ocean in summertime, a favorable pressure pattern can set this potentially dangerous air mass in motion and cause it to rise over the low hills inland from the coast. Though the rise is only about 2,000 feet, it is sufficient, especially with a cold air mass to the west and north to assist the lifting, to trigger the moisture from the ocean-borne air mass, causing downpours that one associates with tropical regions.

FALL HURRICANES

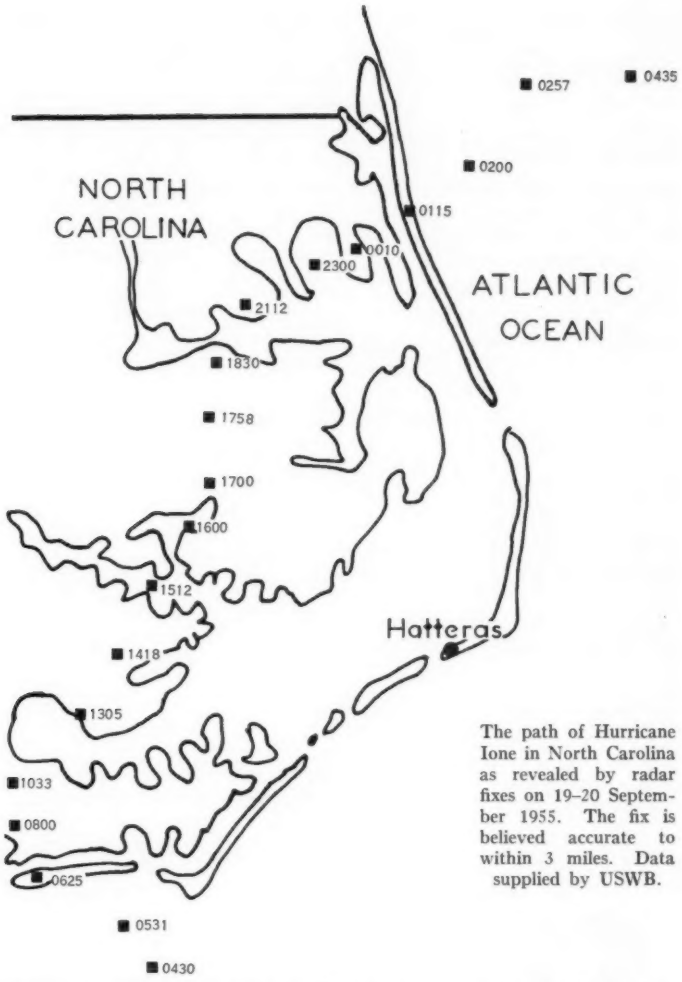
GLADYS—The seventh disturbance of an active storm season in the tropics formed in the western Gulf of Mexico on 4 September east of the central Mexican coast. It followed a course to the north-northwest, coming inland on the 6th near Tampico, Mexico, where very heavy rains caused severe flooding and the loss of several lives. The circulation of this storm brought great quantities of moisture as far north as the Texas coast; heavy rains fell from Galveston southwestward—the Naval Base at Corpus Christi registered 17.02 inches and the tide was 4.5 feet above normal. Streets and beach installations were damaged. Highest winds from Gladys at Corpus Christi were 54 mph. from the north-northeast. The interior of southeastern Texas was also deluged.

FLORA—Hurricane Flora was first located well to the northeast of Puerto Rico on 9 September. It churned northeastward far from any land area as it moved into the North Atlantic to the east of Bermuda, from where a watchful eye was kept on it by the Air Force Reconnaissance Squadron.

HILDA—The ninth tropical storm proved to be the most severe of the season so far in regard to intensity, duration, and lives lost. Hilda was first reported on 13 September to the north of Santo Domingo and to the east of Turks Island in the extreme southeastern Bahama Islands. Pursuing a southwesterly track, it crossed the eastern tip of Cuba on the 14th with winds reported at 90 mph. and emerged in the Caribbean Sea to regain its former energy. Its course was then southwest across the Caribbean to the Yucatan peninsula of Mexico where a recurvature to the west-northwest took place. The hurricane emerged from its second land traverse into the Gulf of Mexico and headed straight for the Tampico area where a third landfall was made on the 18th, just as Ione was threatening the Carolina coasts. Unprecedented flooding occurred in the Tampico area with loss of life placed by the press near one hundred persons.

IONE—The next hurricane of the 1955 season was first reported about 250 miles east of San Juan, Puerto Rico, on 14 September. It took up the familiar tracks of Connie and Diane, making for a North Carolina landfall where it arrived on the morning of 19 September. Its course inland was between Wilmington and Cape Hatteras. The highest wind speed was a gust of 107 mph. reported at the Marine Base at Cherry Point.

Upon crossing the coastline at about dawn, Ione seemed to hesitate and slow its forward progress perceptibly and apparently slid westward. With a rather erratic movement for 19 hours it slowly shifted northeastward across the inlets and bays of eastern North Carolina, and then set off soon after midnight on a track to the east-northeast, never quite reaching the Virginia border before it passed out to sea. Naturally, such behavior was not anticipated as the storm has been previously classified with the energetic Hazel of October 1954, and the forecast of its movement was made on the assumption that it would move northward and then northeastward to give the large industrial cities of the Northeast a battering. Hurricane alerts were



The path of Hurricane Ione in North Carolina as revealed by radar fixes on 19–20 September 1955. The fix is believed accurate to within 3 miles. Data supplied by USWB.

raised to Cape Cod, as the forecasters anticipated an acceleration similar to Carol and Hazel in 1954. But the pattern of a northward-moving hurricane did not appear; the storm center had lost its momentum soon after it reached land and dallied all the daylight hours of the 19th in eastern North Carolina.

At about 1700 a bit of meteorological history was made when Professor John Quincy Stewart, associate professor of astronomy at Princeton University, called his local paper and said that on the basis of facts in front of him, the wind would "not be bad in New Jersey" and that he thought warnings for New Jersey should be lowered and the public should resume a normal schedule. This announcement was soon picked up by news wires and featured in the Tuesday morning press and radio headlines. From then on Ione was Prof. Stewart's storm, and the general public expressed its frustration over the false warnings by acclaiming the Professor as a sort of "national hero-for-a-day."

JANET—The final episode in a very active tropical storm season wrought immense destruction throughout the islands of the Caribbean Sea and on the coasts of Mexico. Just as the furor of Ione was subsiding, the most southerly hurricane circulation of the year was spotted on 22 September about 350 miles southeast of Martinique Island in the Lesser Antilles. On the following day Janet smashed across the chain of islands of the Windward group with winds reported up to 125 mph. Barbadoes and Granada were the chief sufferers; 506 were reported dead. The storm continued westward, traversing the length of the Caribbean before striking the Yucatan peninsula, as Hilda had done 10 days earlier. Excessive rains fell in the mainland area near Tampico, causing floods that made 60,000 homeless and caused over 200 deaths. Mexico's greatest relief operation brought worldwide support. The momentum of Janet was so great that it carried the storm all the way across the Mexican mainland and emerged on the Pacific coast with gale force winds.

USNC–IGY Antarctic Program

(*Continued from page 140*)

IGY Weather Central will serve as an analysis center at which the large-scale and the small-scale features of the atmosphere will be analyzed and studied. The aerological center at McMurdo Sound will have begun a program of analysis and forecasting during the pre-IGY period, using information collected at the few pre-IGY stations which are to be established prior to January 1957. The IGY Weather Central will issue weather advisories and forecasts to help in the planning and carrying out of operations on land, sea, and in the air. These advisories and forecasts will be made available to all expeditions, as required. Although the network of stations will be relatively sparse and our knowledge of Antarctic meteorology limited, for the first time there will be a possibility of collecting enough weather data for a reliable analysis and forecasting program to be developed.

Each Antarctic meteorological station will be supplied with the following instrumentation:

Rawinsonde equipment (self-tracking)
Pilot balloon equipment
Mercurial barometer
Microbarograph
Aneroid altimeter
Assorted thermometers (to − 130° F.)
Thermograph
Wind recording system
Sunshine duration recorder
Nephoscope
Ceiling projector
Infra-red hygrometer
Precipitation gage
Snow stakes
Hemispheric radiometer
Net radiometer
Pyrheliometers
Inverted pyrheliometer for albedo

At the Little America station wind data will be recorded for two or more levels, and a tower will be used for support of temperature sensing elements at various heights up to 60 feet to study the vertical structure of the atmosphere.

The Little America station and the Byrd Land station will have normal incidence pyrheliometers.

Work is currently progressing on techniques for measuring total atmospheric ozone and surface carbon dioxide. It is hoped that such measurements can be made at least at the Little America station.

Selection of personnel for the IGY Antarctic program is now in progress. The following types of positions for the meteorology program are available: meteorologist, analyst, rawinsonde technician, rawinsonde observer, and chartman-observer. Anyone interested in participating during 1956–57, or during 1957–58, is invited to write to Chief, U. S. Weather Bureau, Washington 25, D. C. or the address below. Openings are also available in the other scientific disciplines—aurora and airglow, cosmic rays, geomagnetism, glaciology, ionospheric physics, rocket exploration, seismology, and gravity. Qualified individuals should address inquiries in these fields to: Secretary, Personnel Selection Board, USNC-IGY, National Academy of Sciences, 2101 Constitution Ave., Washington 25, D. C.

NEW BOOKS RECEIVED

Charles and Ruth Laird, *Weathercasting*, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1955. 163 p. $3.95.

"The aim of *Weathercasting* is to furnish material to the amateur meteorologist which will help him get a good start in a fascinating hobby."

U. S. Weather Bureau, *Meteorology and Atomic Energy*, Government Printing Office, Wash., D. C., 1955. 169 p. $1.00.

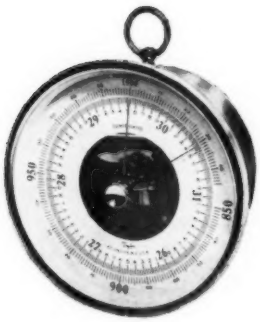
"It is the purpose of this publication to provide a summary of some of the meteorological techniques that are available and to describe their applications to the possible atmospheric pollution deriving from the use of atomic energy."

Eric Sloane, *Eric Sloane's Almanac and Weather Forecaster*, Little, Brown and Company, Boston, 1955. 169 p. $3.50.

"In doing this book, I tried to copy the format of old almanacs, because I believe that, like myself, most people enjoy the way weather data and rural observations can join together to make pleasant reading."

T. Bedford Franklin, *Climates in Miniature: A Study of Micro-climate and Environment*, Philosophical Library, New York, 1955. 137 p. $3.75.

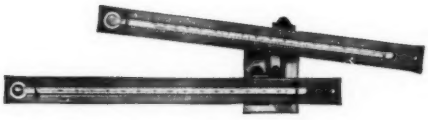
"As its name implies the study of micro-climates is the study of the climate of a very small area, and whether our interests are in the animal, bird, and insect life round our homes, or just in pure gardening there is scope in micro-climates for all of us."



Weather Bureau Type Instruments

No. 306 Meteorological Barometer. U. S. Weather Bureau type. Brass case has a 5-inch dial graduated in both inches and millibars. Range: 26 to 31.5 inches and 850 to 1060 millibars. Best grade movement, compensated for temperature. For sea-level to 3,000 ft. **$38.50**

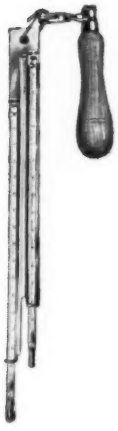
No. 307–8 For elevations 2,000–6,000 or 4,900–9,500 ft. **$44.00**



Official Thermometer

No. 101 U. S. Weather Bureau type. Mercury filled tube 10½ inches long. Graduations etched on stem from −40° to +130° F. Stainless steel backing with brass support. Also available with red spirit tube. **$5.00**

No. 111 Maximum-minimum Thermometers. U. S. Weather Bureau type. Set consists of mercury-filled maximum thermometer with a special constriction for registering highest reading, an alcohol-filled minimum thermometer for registering the lowest reading, and a convenient support. **$25.00**



No. 503 Rain and Snow Gage. U. S. Weather Bureau type. Standard gage has 8-inch brass collector and funnel, inner measuring tube, and copper overflow can, 24 inches overall height. Capacity 20 inches. Red cedar measuring stick **$30.00**

No. 504 Tripod Support for rain gage **$7.50**

No. 208 Sling Psychrometer. U. S. Weather Bureau type. Two matched thermometers, a wet bulb and a dry bulb, are mounted on a stainless steel backing. Handle and swivel attached for whirling. Range: −20° to +120° F. With psychrometric tables. **$10.00**

194 Nassau Street
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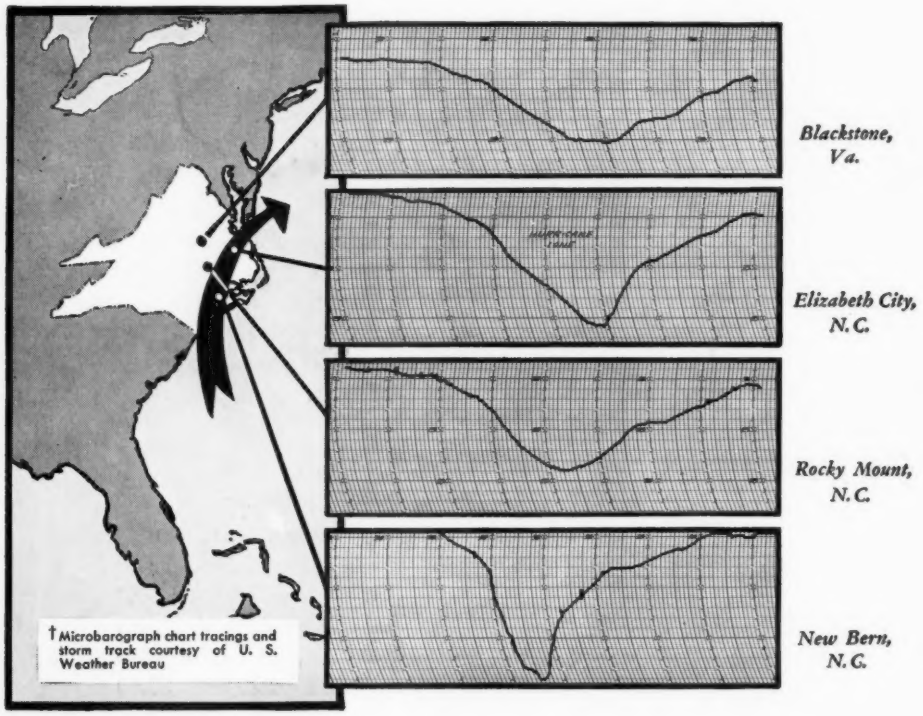
Science Associates


Blackstone, Va.
Elizabeth City, N. C.
Rocky Mount, N. C.
New Bern, N. C.
† Microbarograph chart tracings and storm track courtesy of U. S. Weather Bureau

HURRICANE IONE'S PROFILE AS SHE HIT THE EAST COAST...

Recorded† on the Bendix-Friez Microbarograph

The "Highs" and the "Lows" of atmospheric pressure influence our weather. From them come the variations in temperature, wind, sunshine, rain and relative humidity. The four charts you see above show the atmospheric pressure changes caused by Hurricane Ione as she swept across the coastal areas of Virginia and North Carolina. The deeper the dip on the chart—the lower the pressure, and consequently, the more severe the weather. Moving in a north-northwesterly direction, Ione crossed the coastline on the morning of September 19. Highest winds were estimated to be 110 m.p.h. in gusts. The gale area extended nearly 200 miles to the north. By noon, September 20, Ione was out in the Atlantic again, her havoc over land completed.

The Bendix-Friez* Microbarograph—built to U. S. Weather Bureau standards—shows clearly and precisely the Highs and the Lows of pressure which pass an area. It can be adjusted to make daily, 4-day . . . or weekly recordings.

Universally accepted as the finest instrument of its kind, the Microbarograph is only one of many precise weather instruments made by Bendix-Friez for government, industry and home use. In addition, Bendix-Friez manufactures many other *precision-type* products such as thermistors, pressure switches, Vortex thermometers and other indicating and recording equipment.

If you have a problem in weather instrumentation or precision manufacturing, Bendix-Friez can help you. Your inquiry is invited.

*T.M.

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